

LOCKHEED MARTIN



Friction Stir Process Mapping Methodology

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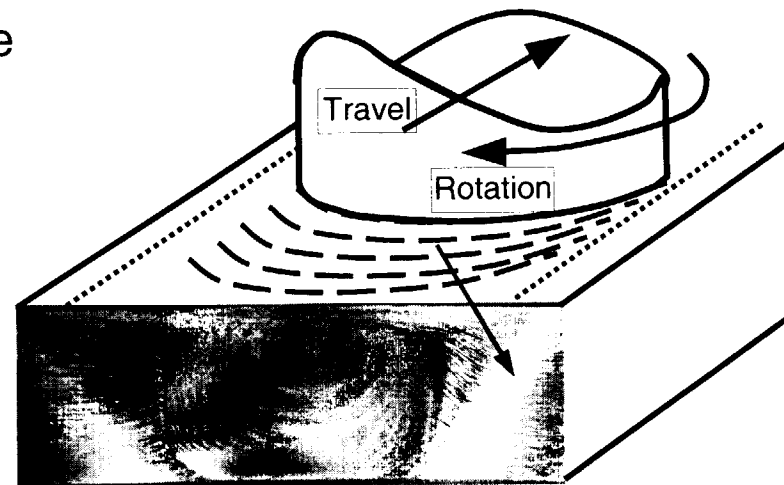
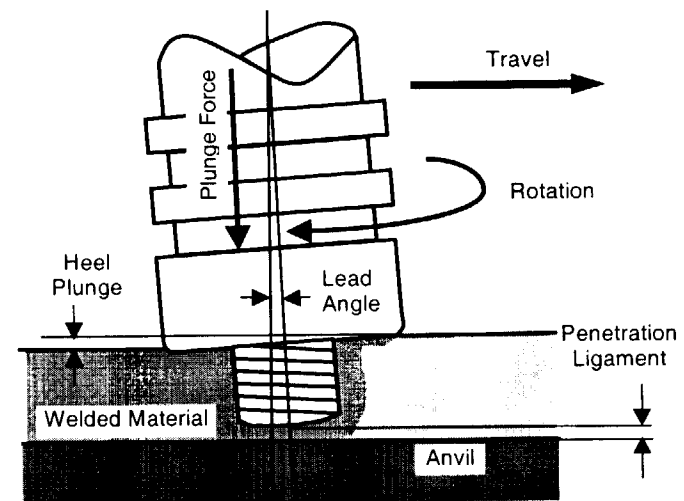
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- Friction Stir Welding (FSW)
 - FSW is a solid-state process using a rotating tool with a shoulder and a projecting pin.
 - The pin tool is rotated and plunged into the joint until the shoulder contacts the top surface.
 - The frictional heating between the pin tool and the joint plasticizes the material in the local region near the pin.
 - The material at the weld centerline is joined through a combination of forging processes that occurs in the local region of the pin tool.
 - Three significant parameters: spindle speed, travel speed, plunge load or plunge position

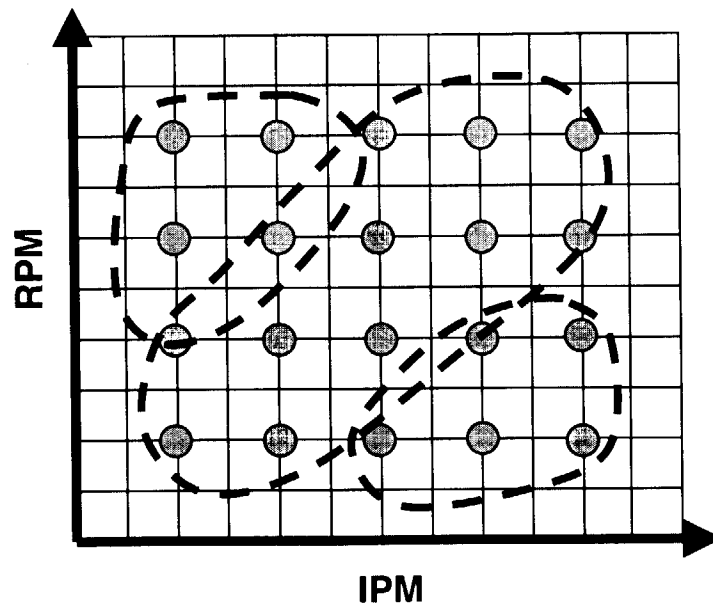




FSW Process Maps



- A process map summarizes the weld process performance for a given pin tool geometry and joint configuration.
- Targeting a consistent penetration ligament, the process is simplified into two parameters: travel speed and rotation speed.
- Other parameters, such as plunge force, traverse force, weld nugget geometry, NDE response, and mechanical properties are assumed to be dependent variables.



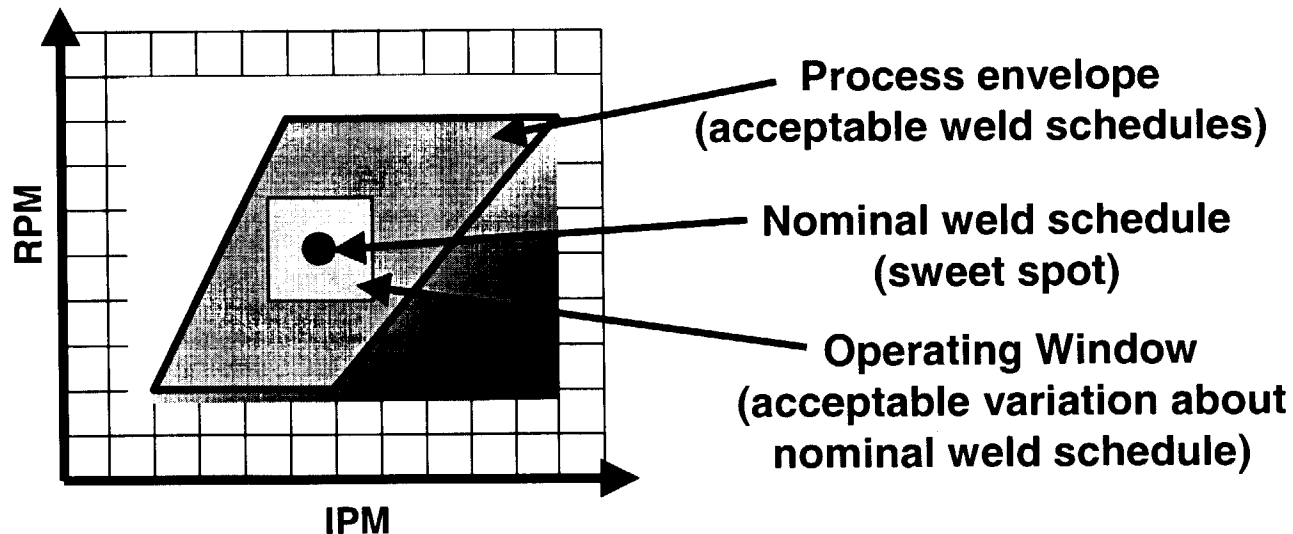
- **YELLOW:** Unusual flow patterns, unstable position and process loads, excessive flash, poor mechanical properties
- **GREEN:** Symmetric flow patterns, stable position and process loads, good strength
- **RED:** NDE rejections, volumetric defects, poor strength, excessive process loads



FSW Process Maps

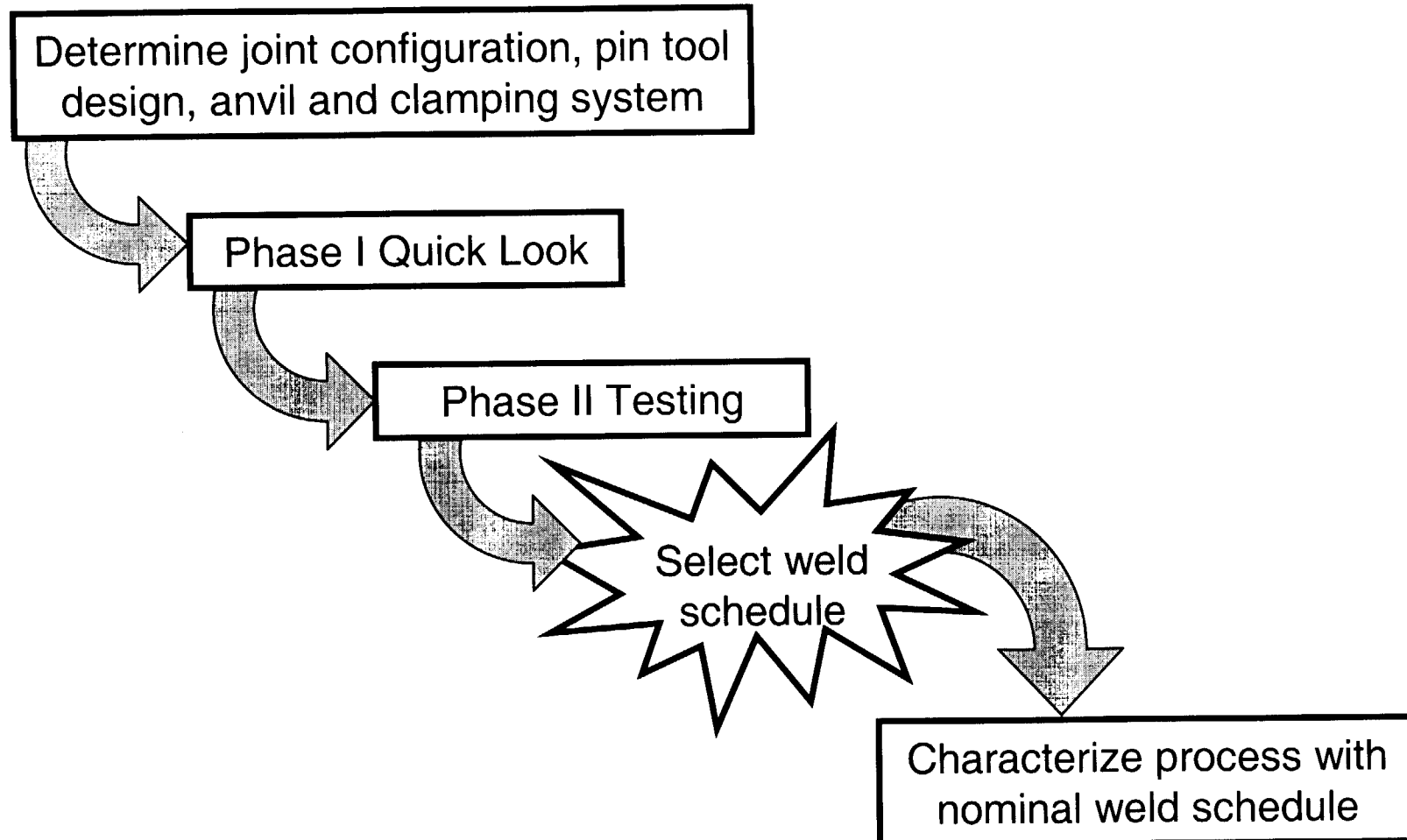


- A selected rpm/ipm combination (weld schedule) provides a specific nugget geometry, heat input, and mechanical strength.
- The selected nominal weld schedule, or sweet spot, is the best compromise between process stability, mechanical strength, NDE response, and machine capability.
- Once the nominal schedule is selected, process loads and heel positions are explored to determine their acceptable operating windows.
- Statistical process control in conjunction with the process map data provides quality control and grounds for reduced NDE requirements.





- Methodology Overview

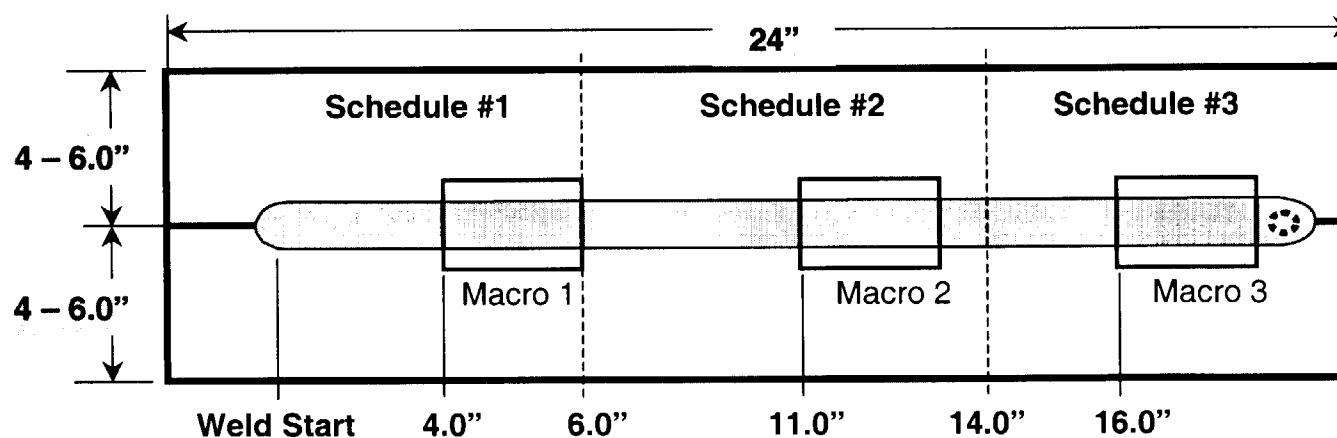




Phase I Quick Look



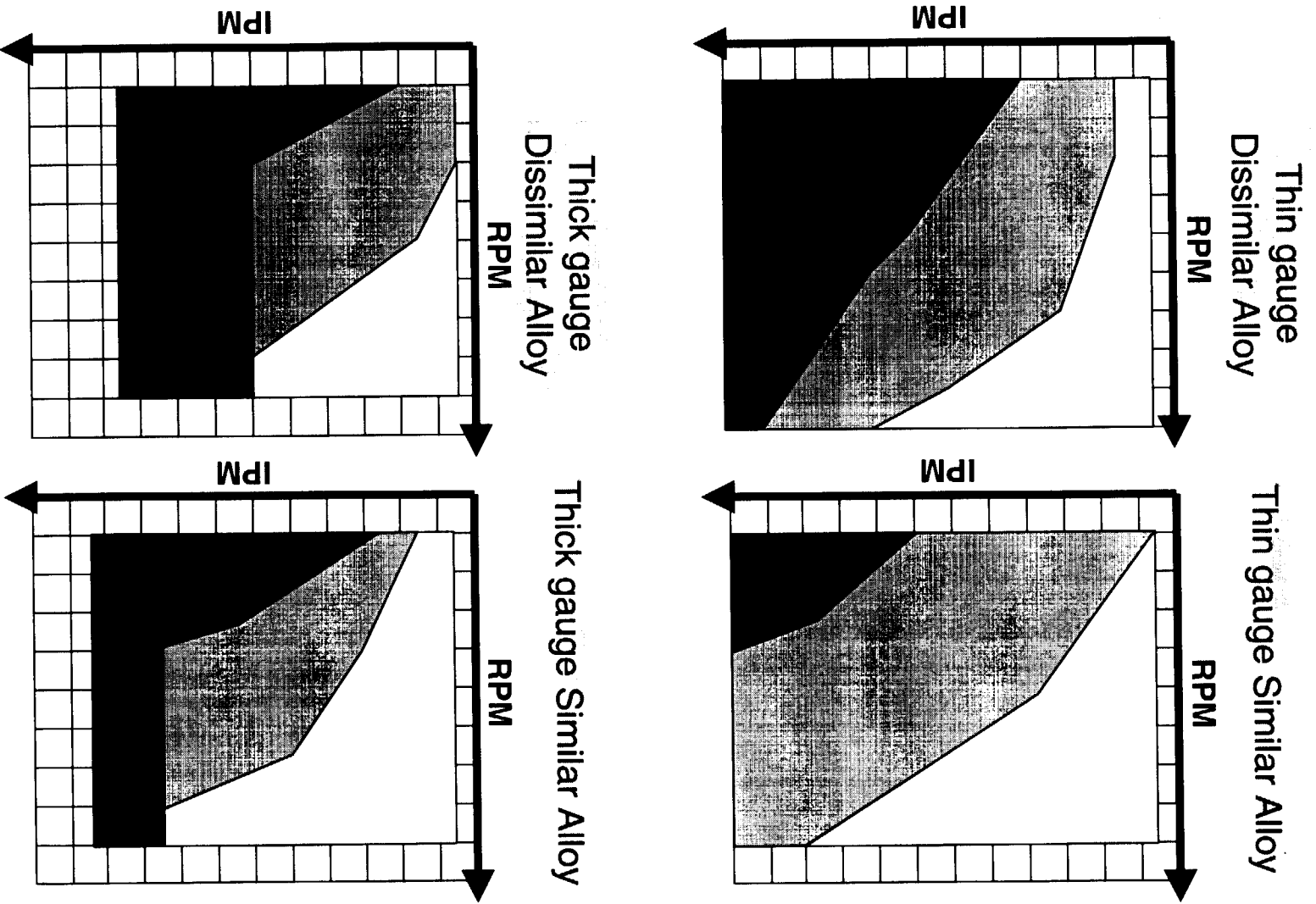
- The “quick look” provides a general overview of the process map
 - Three weld schedules are performed on a 24 inch long test panel
 - Weld schedules are performed “hot” to “cold” by changing the travel speed (constant rotation speed)
 - Metallographic samples are excised near the end of each weld schedule





Phase I Quick Look

- Yellow, Green, and Red regions are delineated based on the metallographic data from the Quick Look welds.



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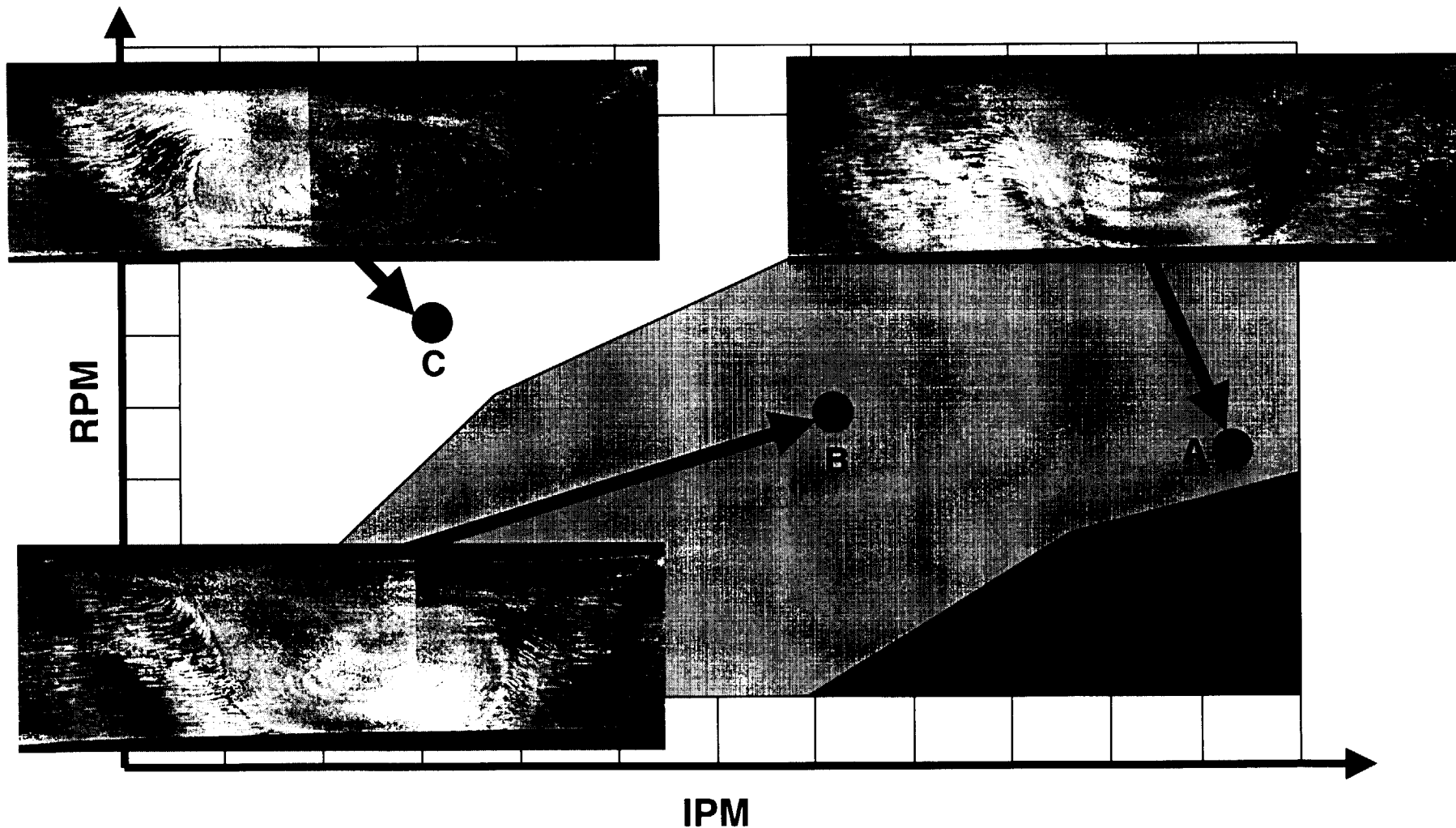
Friction Stir Process Mapping Methodology



Phase I Quick Look



- Thin gauge similar alloy configuration
 - Low (A), medium (B), and high (C) heat input

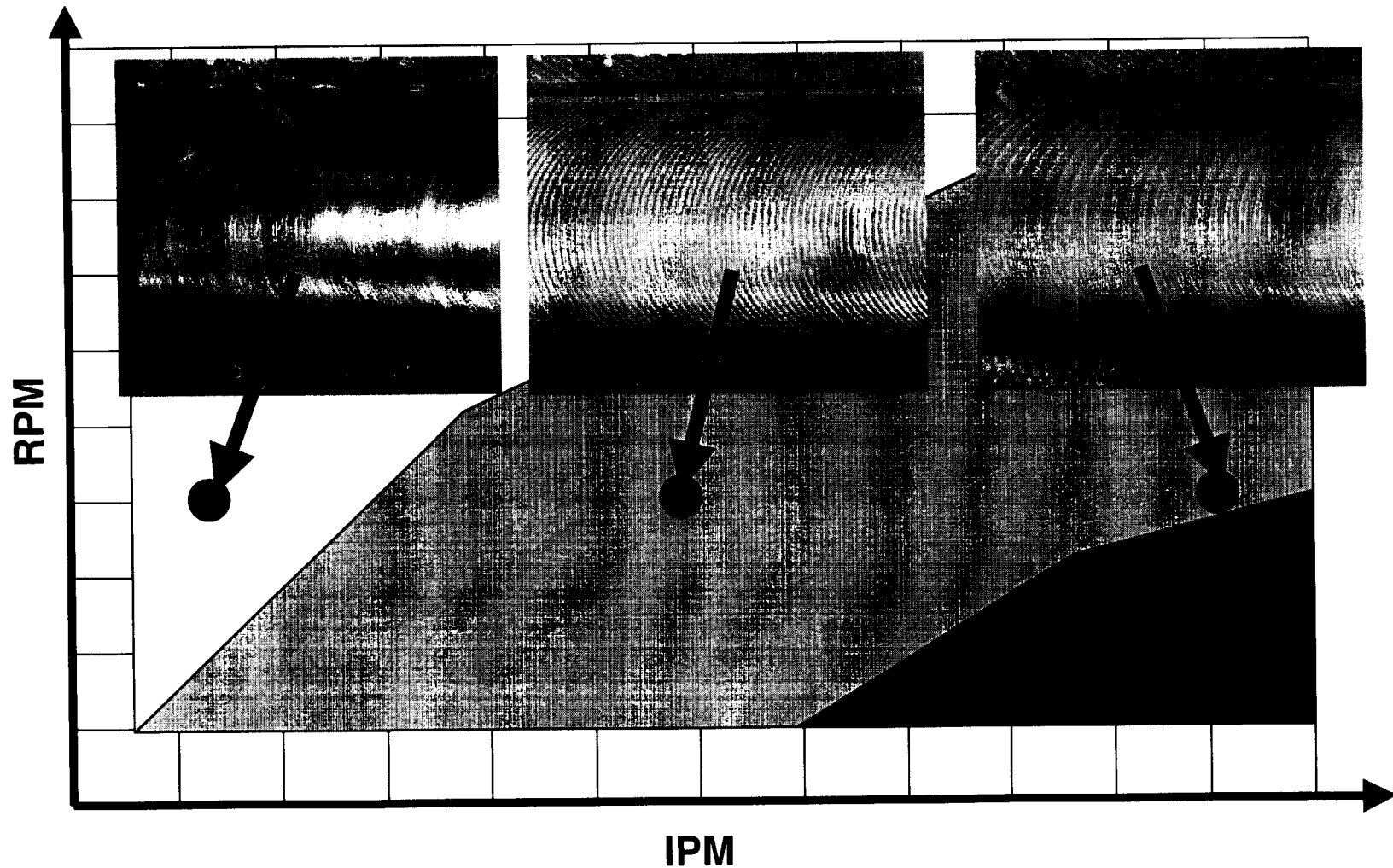




Phase I Quick Look



- Thin gauge similar alloy configuration
 - Heel plunge vs. travel rate

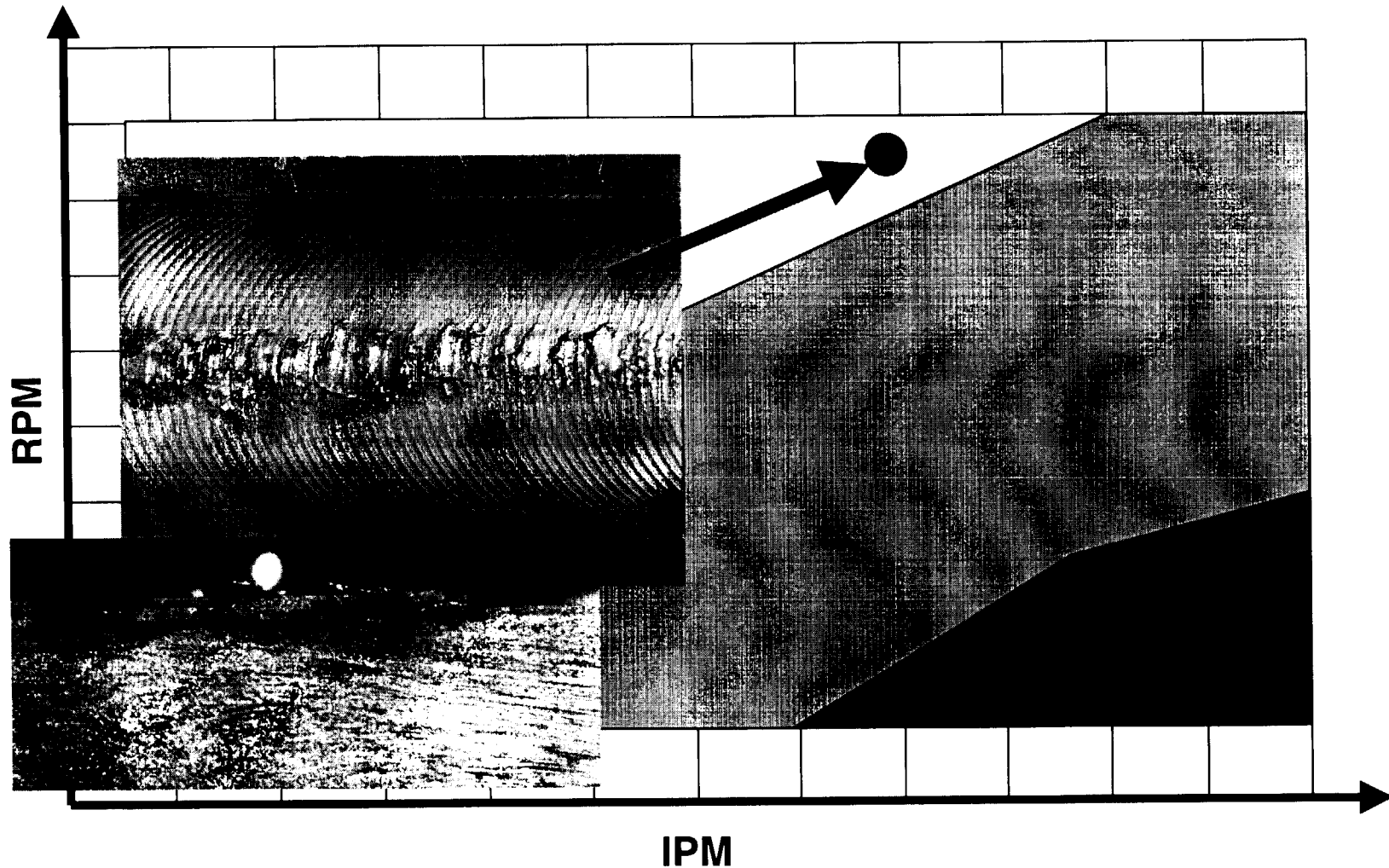




Phase I Quick Look



- Thin gauge similar alloy configuration
 - Scaling/ Galling

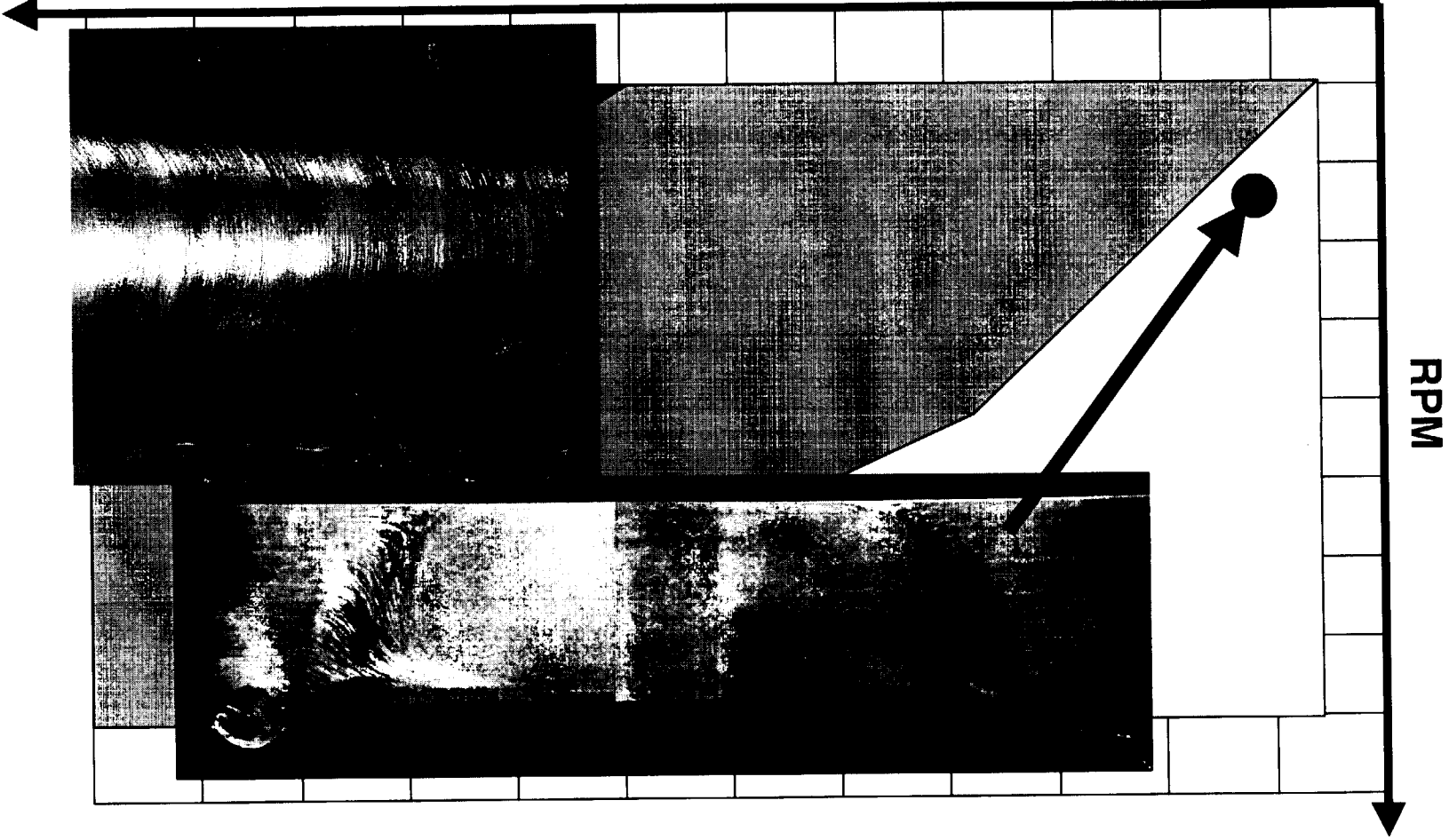




Phase I Quick Look

LOCKHEED MARTIN

- Thin gauge similar alloy configuration
 - Large Weld Nugget and Excessive Flash



Friction Stir Process Mapping Methodology

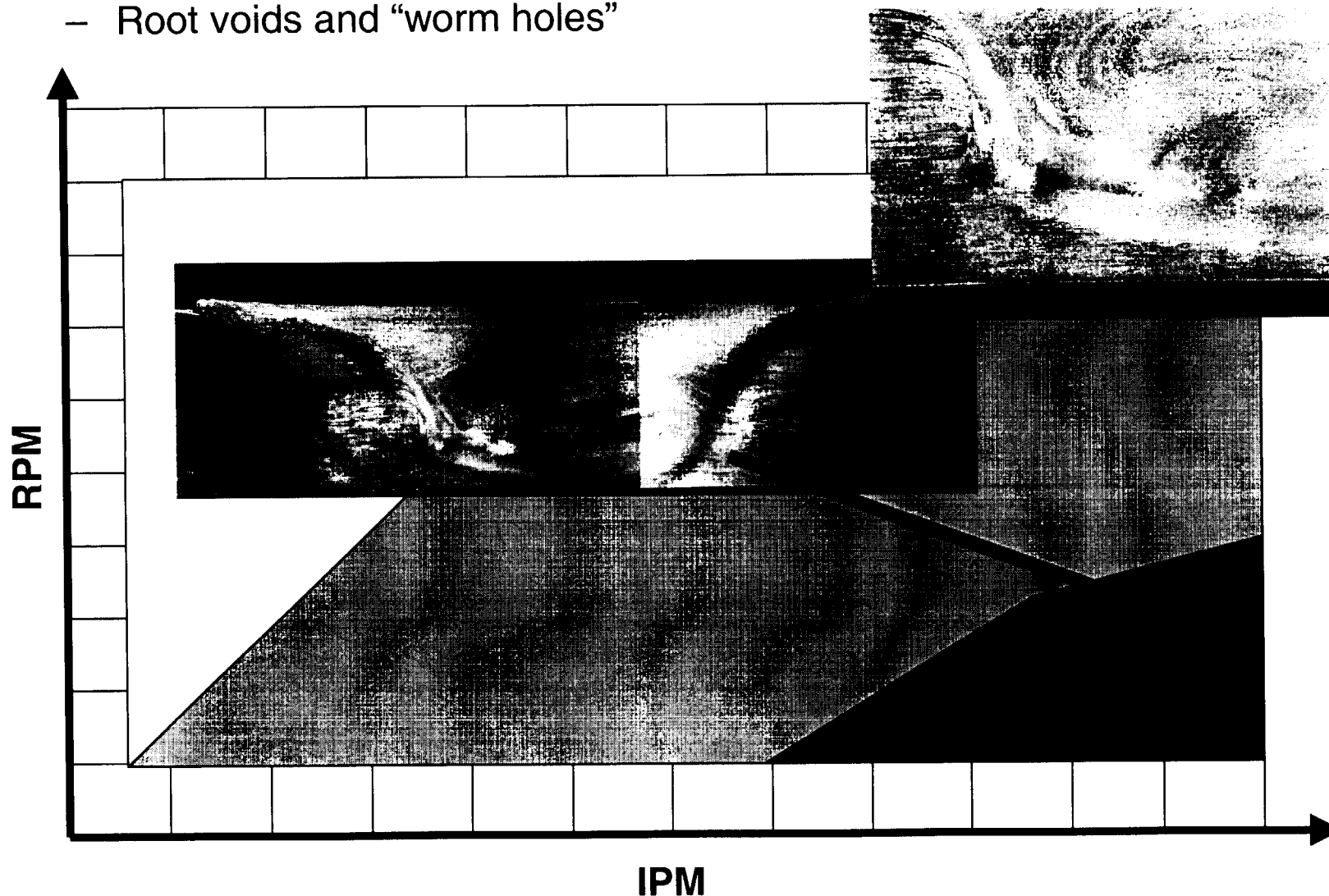
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Phase I Quick Look



- Thin gauge similar alloy configuration
 - Root voids and “worm holes”

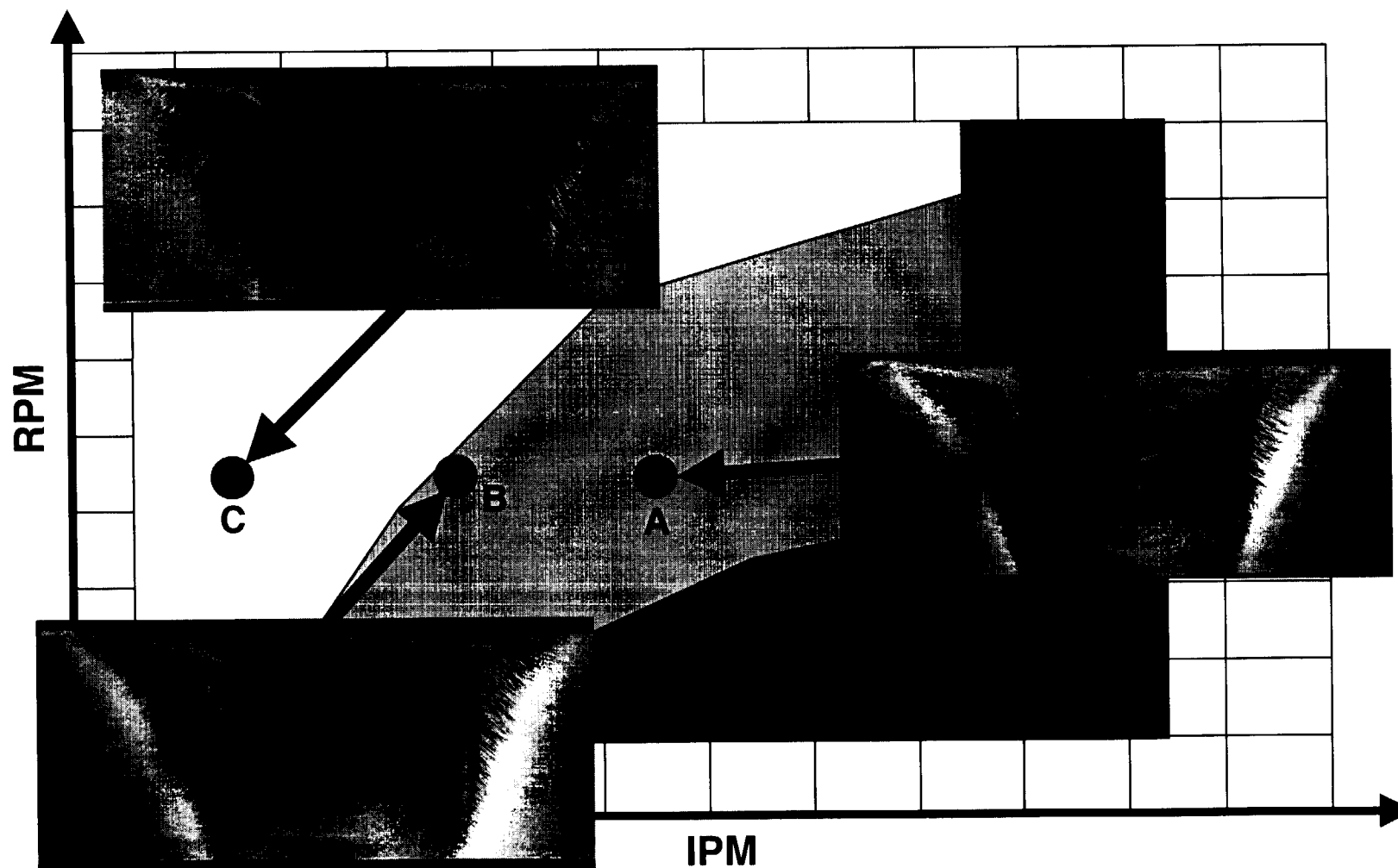




Phase I Quick Look



- Thick gauge similar alloy configuration
 - Low (A), medium (B), and high (C) heat input

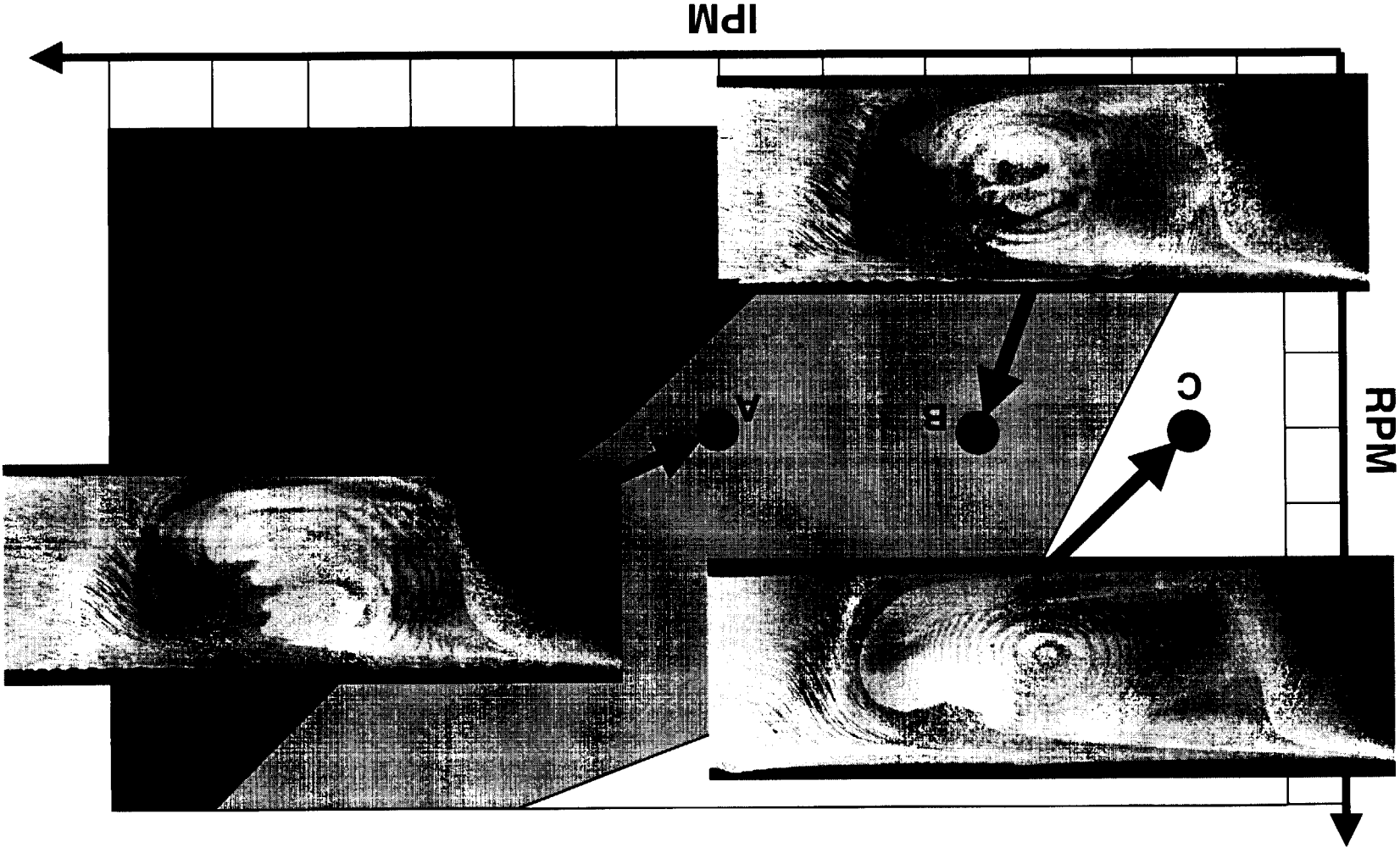




Phase I Quick Look



- Thin gauge dissimilar alloy configuration
 - Low (A), medium (B), and high (C) heat input



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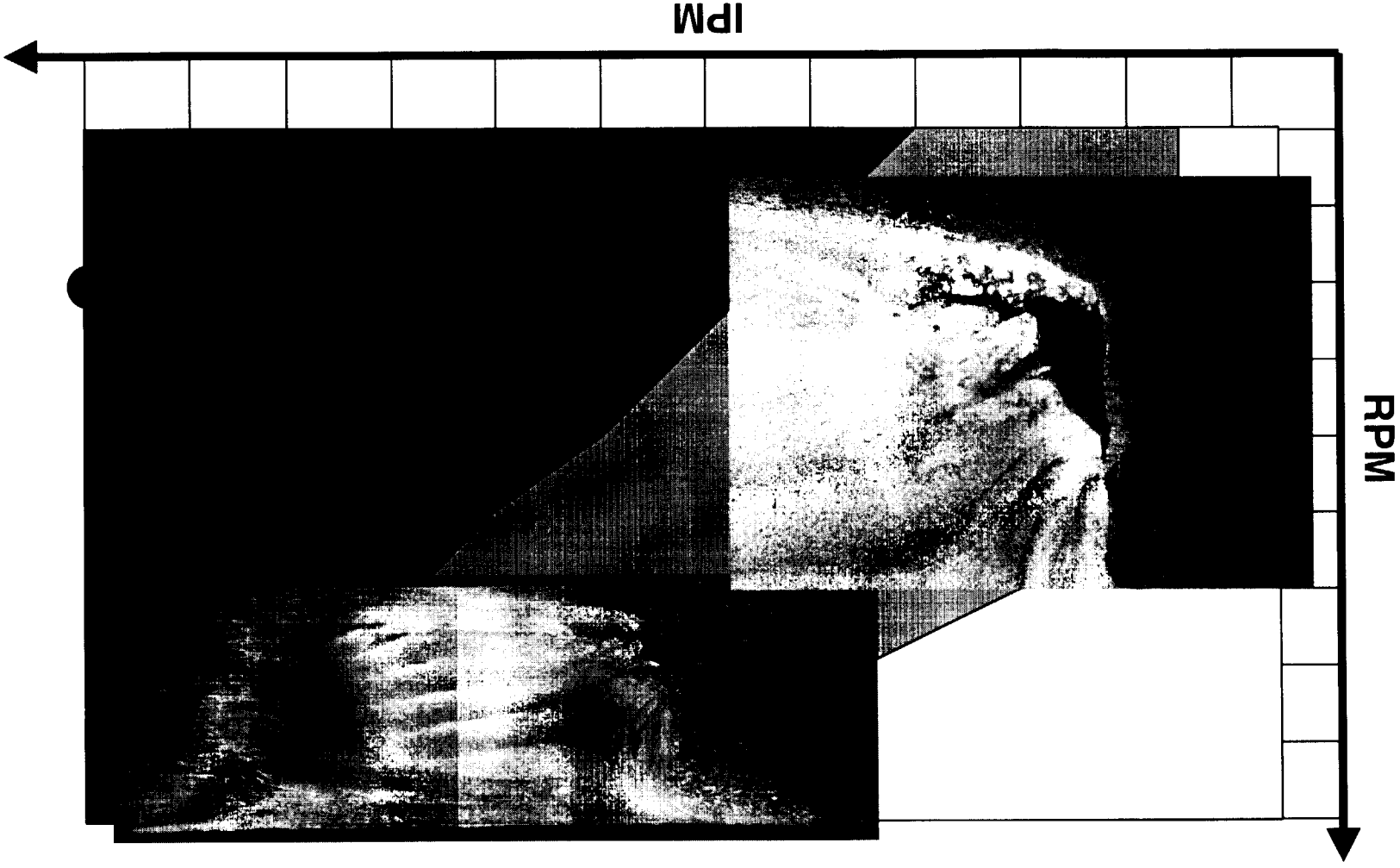
Friction Stir Process Mapping Methodology



Phase I Quick Look



- Thin gauge dissimilar alloy configuration
 - Root void and “worm hole”



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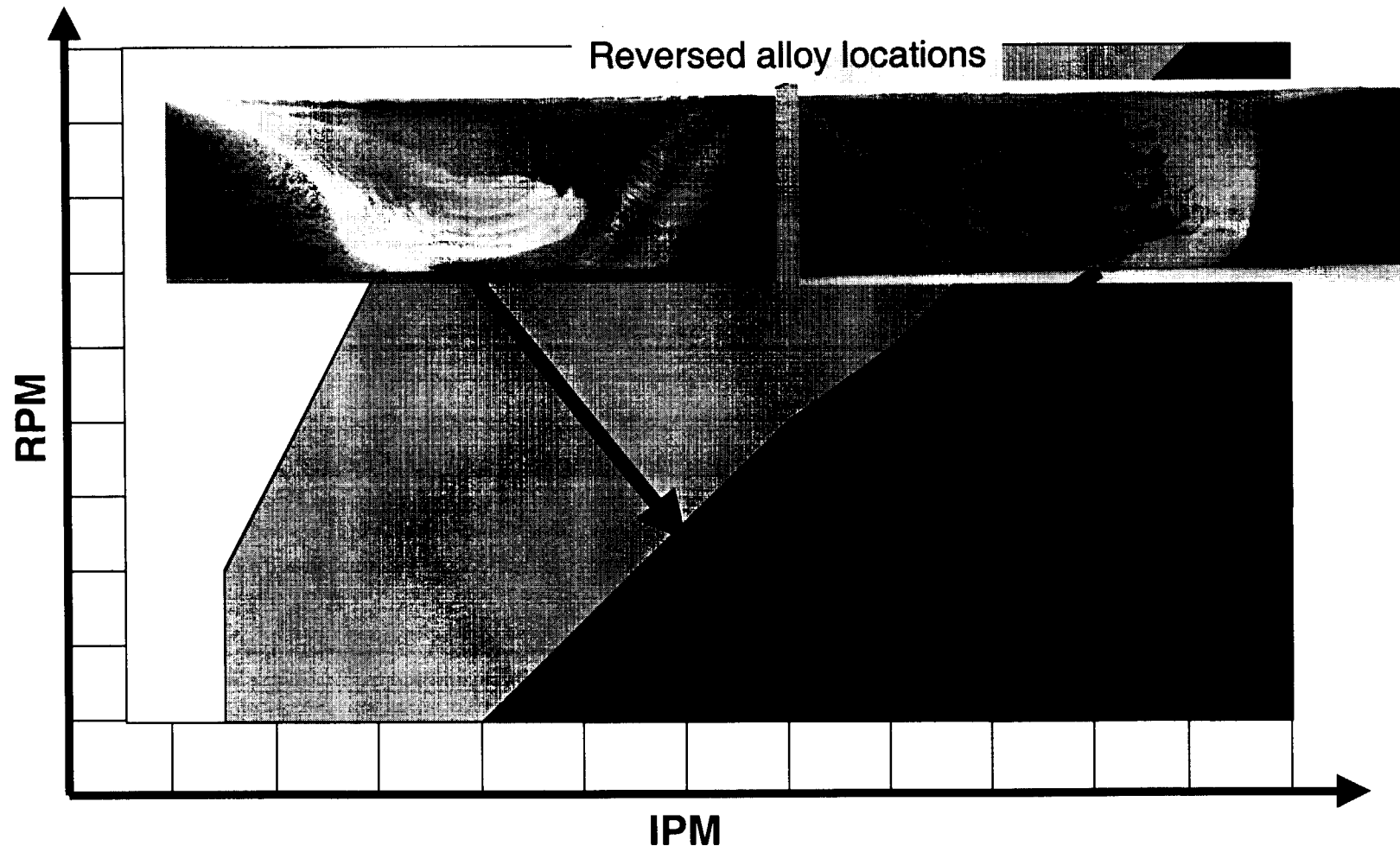
Friction Stir Process Mapping Methodology



Phase I Quick Look



- Thin gauge dissimilar alloy configuration
 - Irregular nugget flow
 - Location of particular alloy influences flow within the nugget

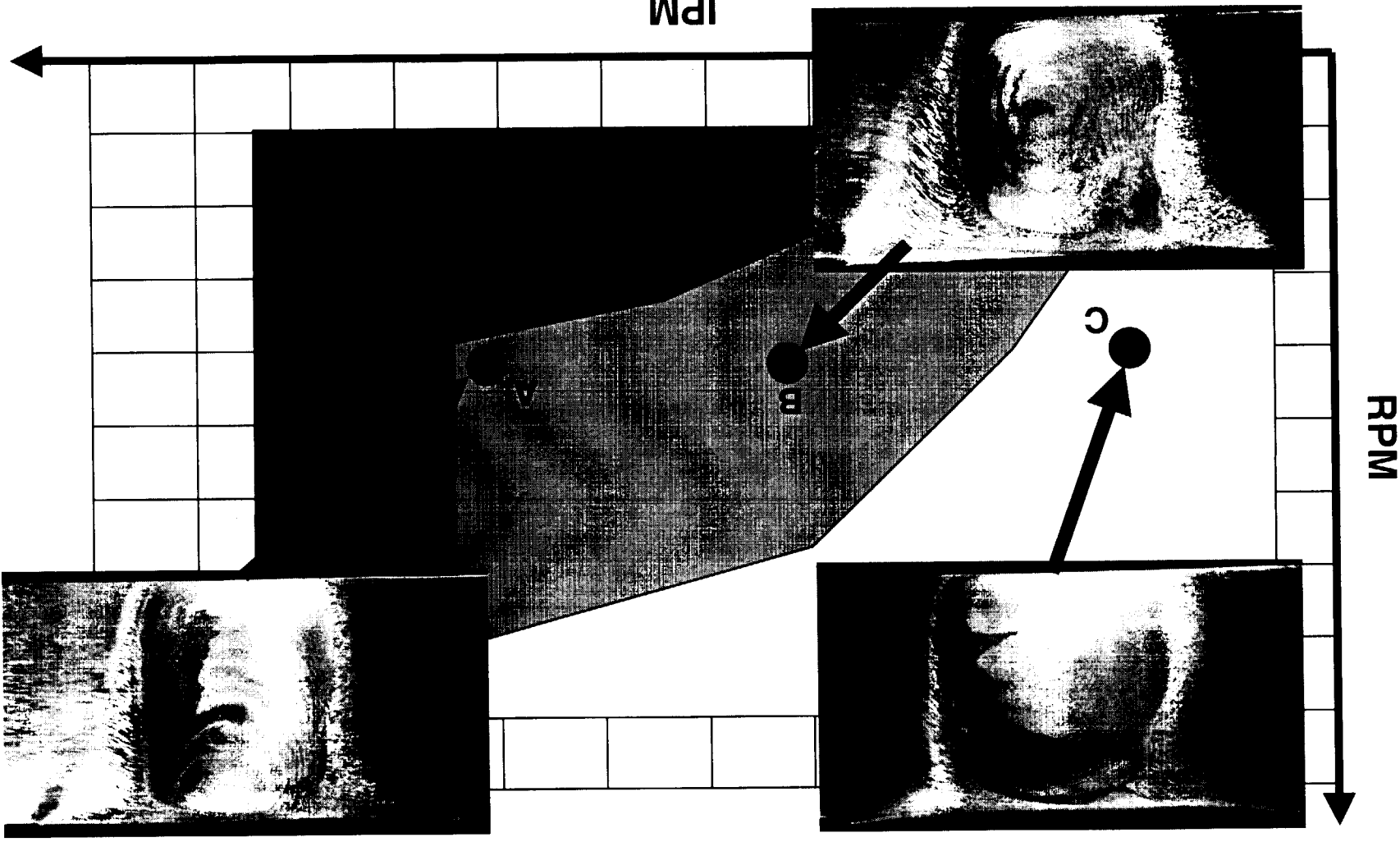




Phase I Quick Look

LOCKHEED MARTIN

- Thick gauge dissimilar alloy configuration
 - Low (A), medium (B), and high (C) heat input



Friction Stir Process Mapping Methodology

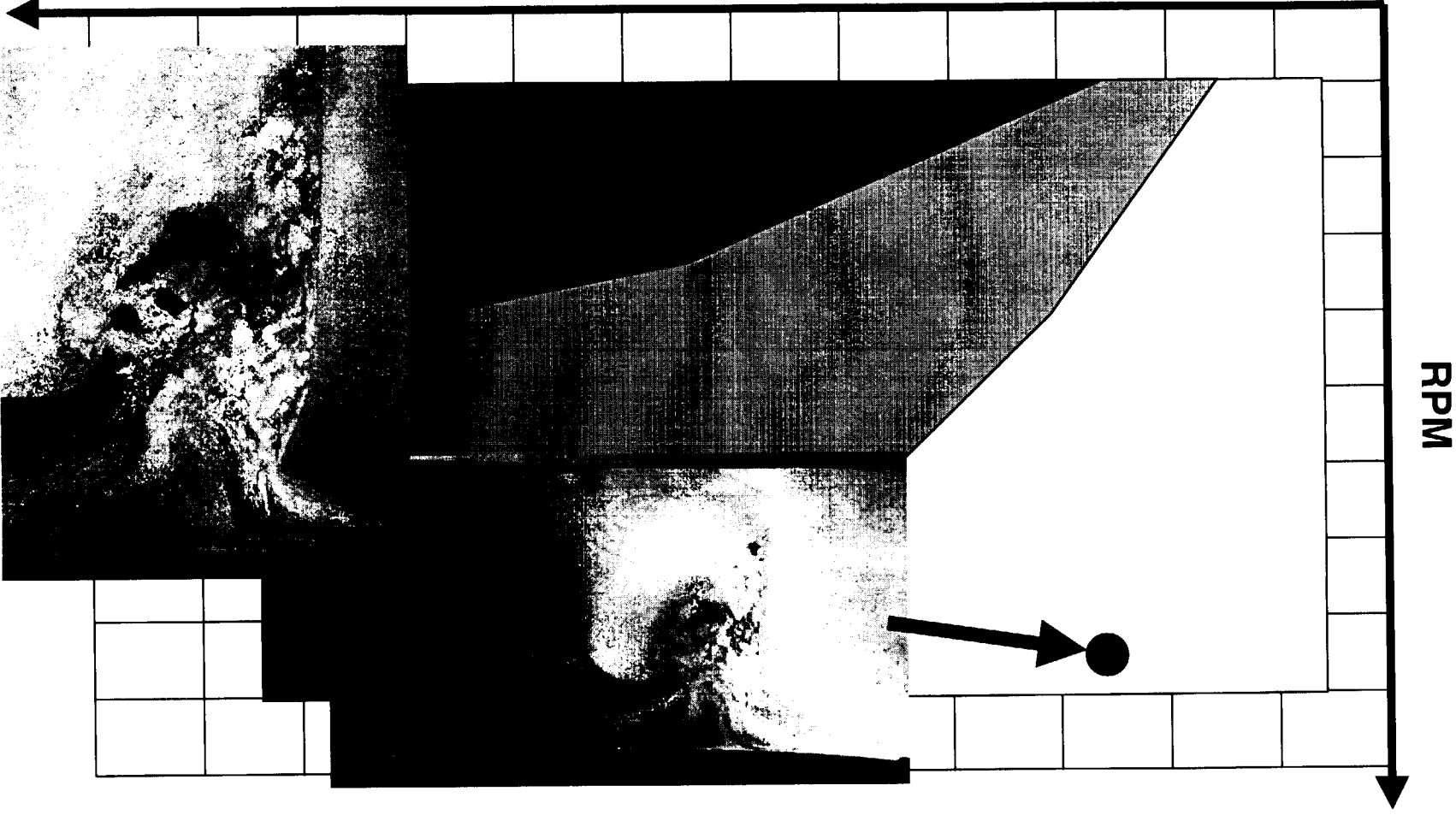
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Phase I Quick Look

LOCKHEED MARTIN

- Thick gauge dissimilar alloy configuration
 - High heat input weld/ collapse weld nugget with “worm holes”



Friction Stir Process Mapping Methodology

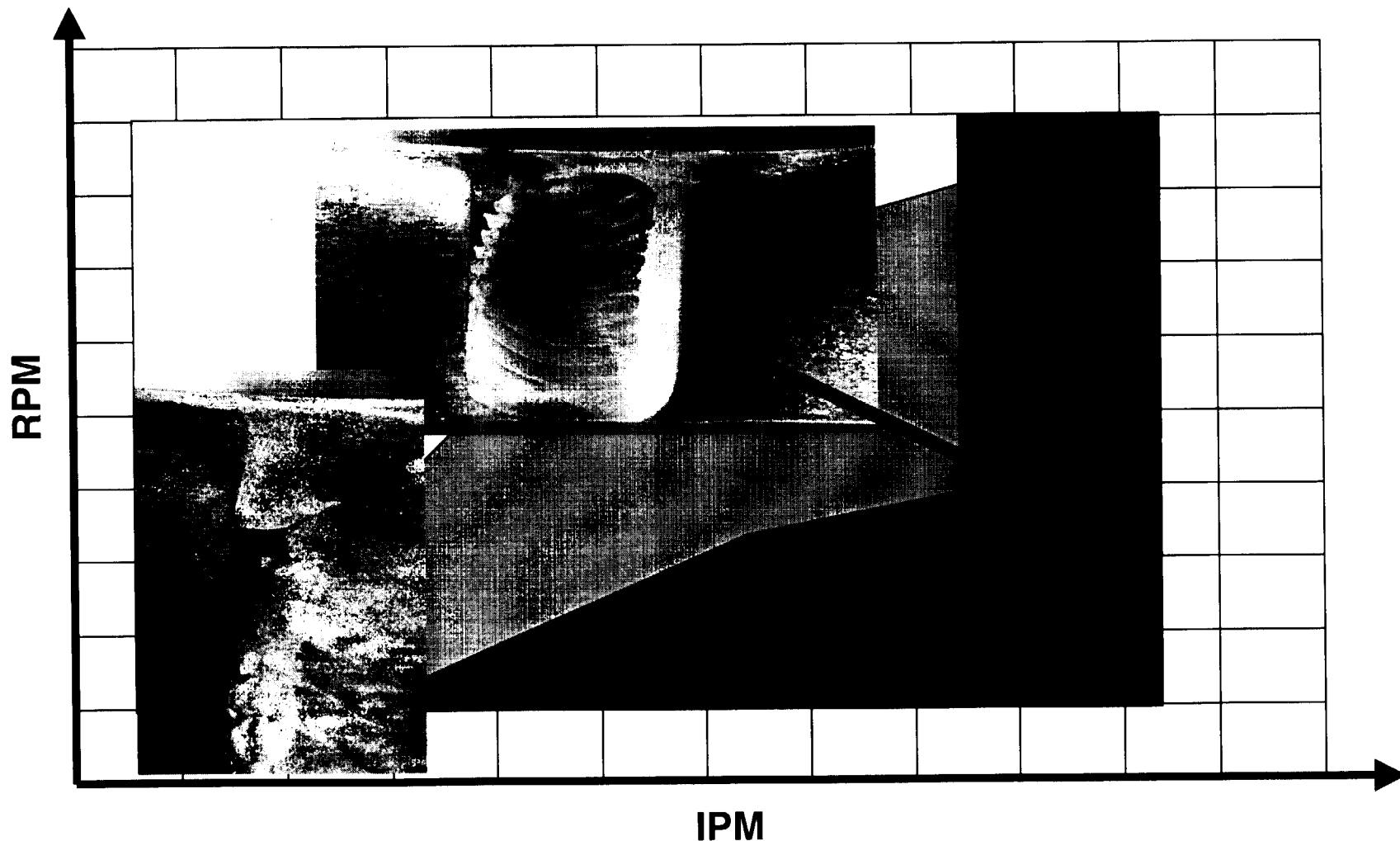
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Phase I Quick Look



- Thick gauge dissimilar alloy configuration
 - Low Heat Input Weld with “Worm Holes”

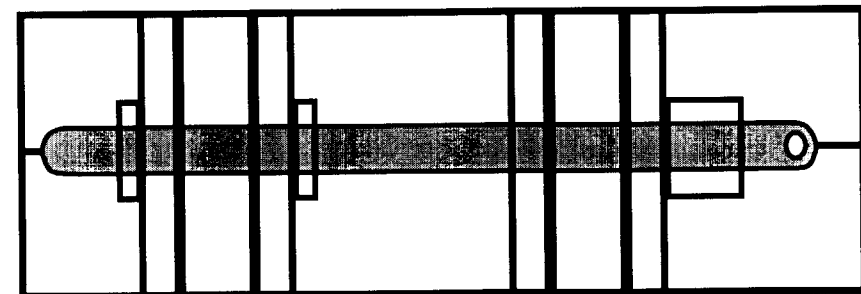
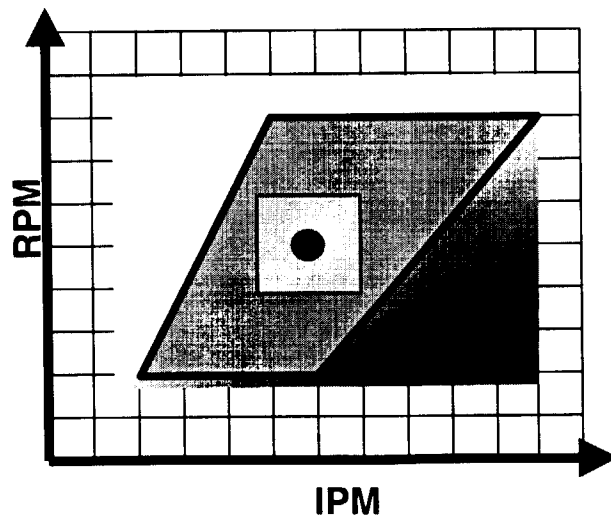




Phase II Testing



- Weld schedules that provide acceptable metallographic profiles from Phase I are performed on 24" long test panels.
 - The longer weld provides adequate time for weld to reach stability
 - More reliable NDE response and tensile tests
 - Process load data becomes more consistent
- Tensile tests are conducted at the expected service temperatures of the weld
- These tests define the process envelope and begin to focus in on the "sweet spot"



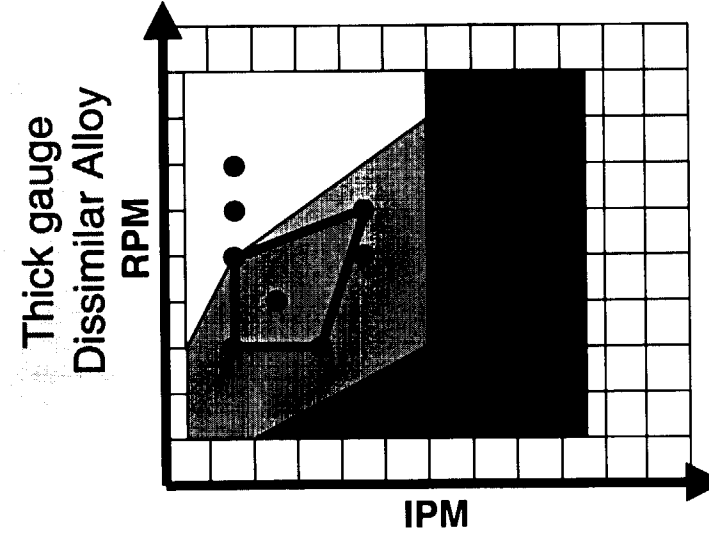
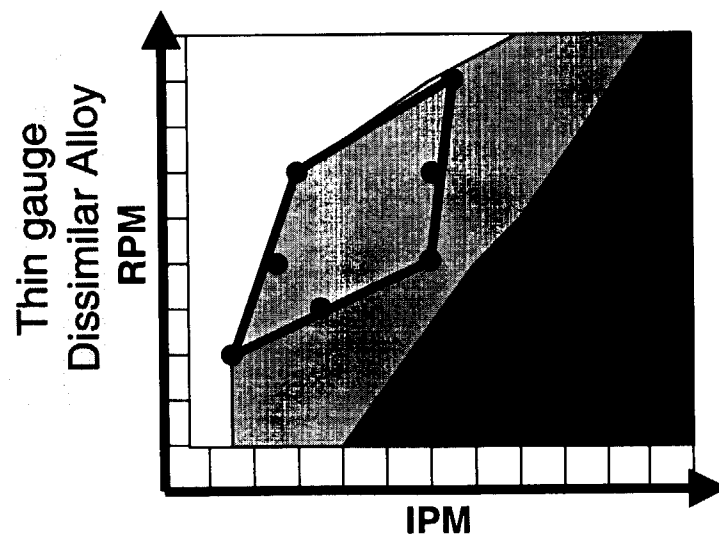
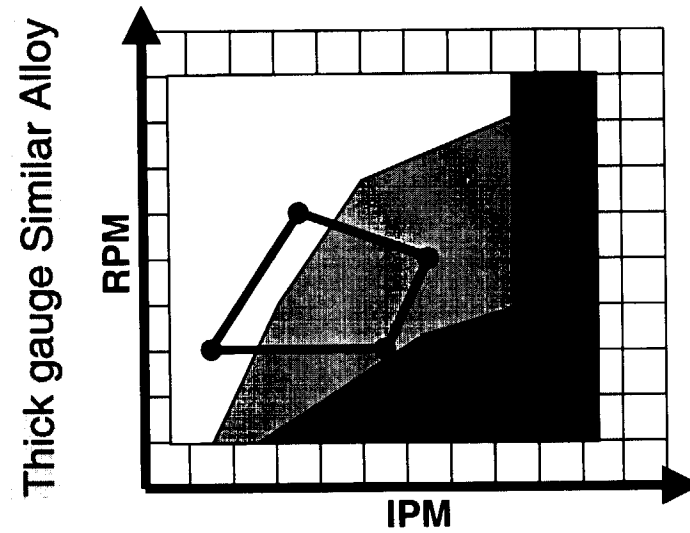
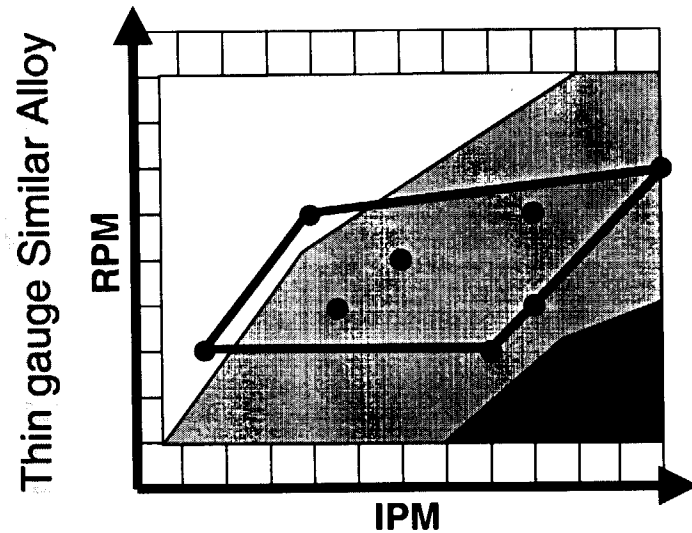
12"x24" Test Panel



Phase II Testing



- The process envelope is delineated using the Phase II test data
 - Mechanical strength, NDE, and tool performance are factors to consider

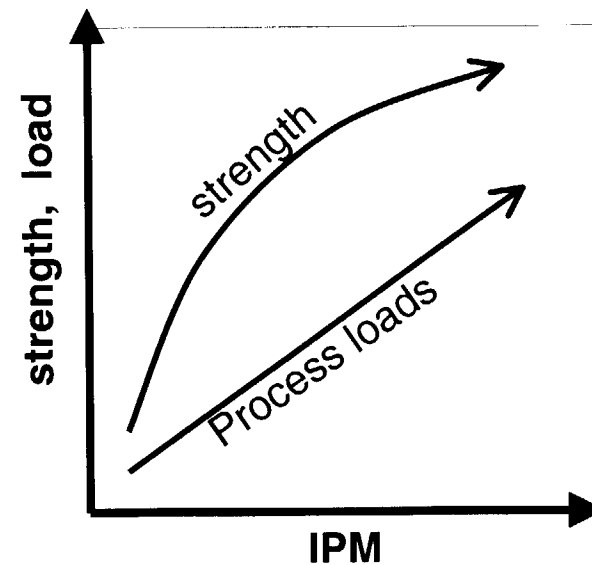
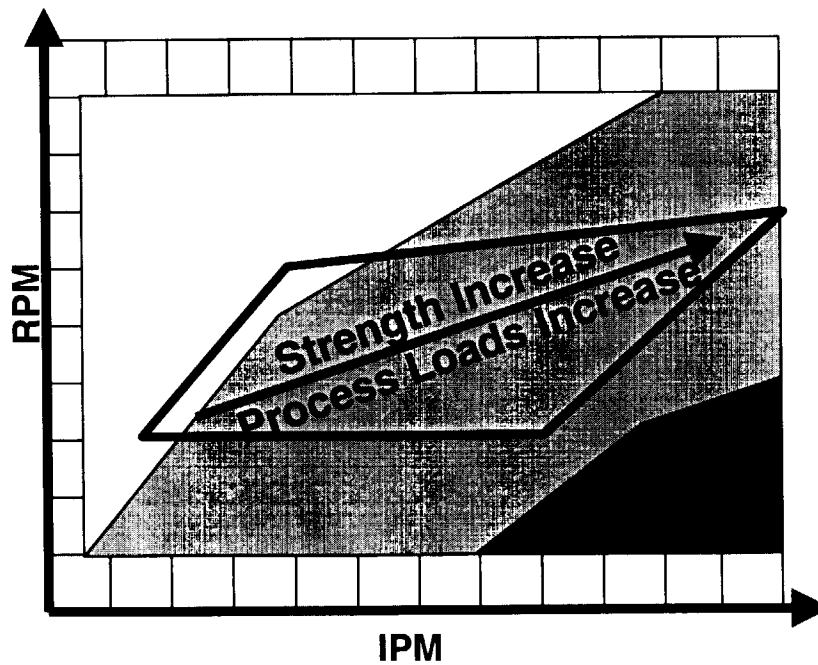




Phase II Testing



- Tensile strength increases with faster travel speeds
 - Cryogenic strength is more sensitive than room temperature strength to heat input
- Process loads, especially traverse loads, increase with travel speed
- The ability to perform cold welds depends on the machine's control system response

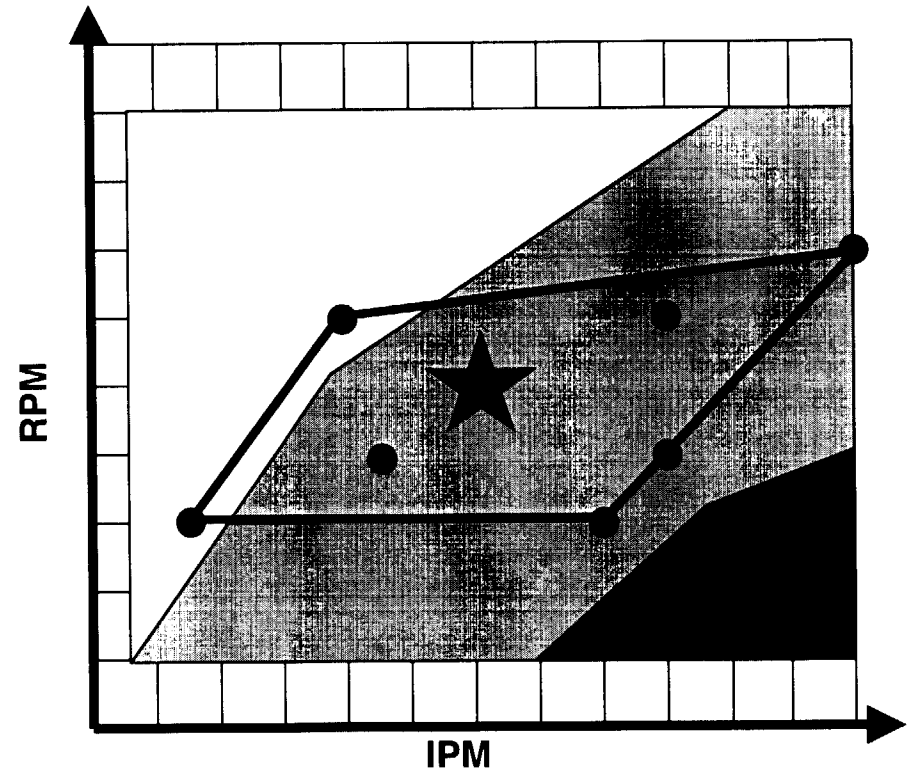




Weld Schedule Selection

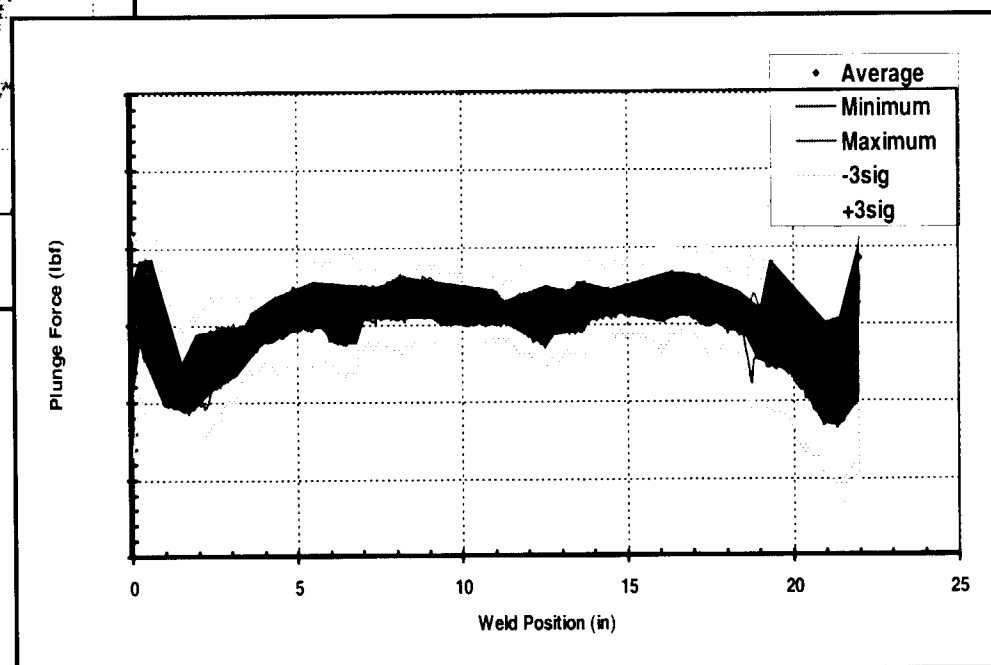
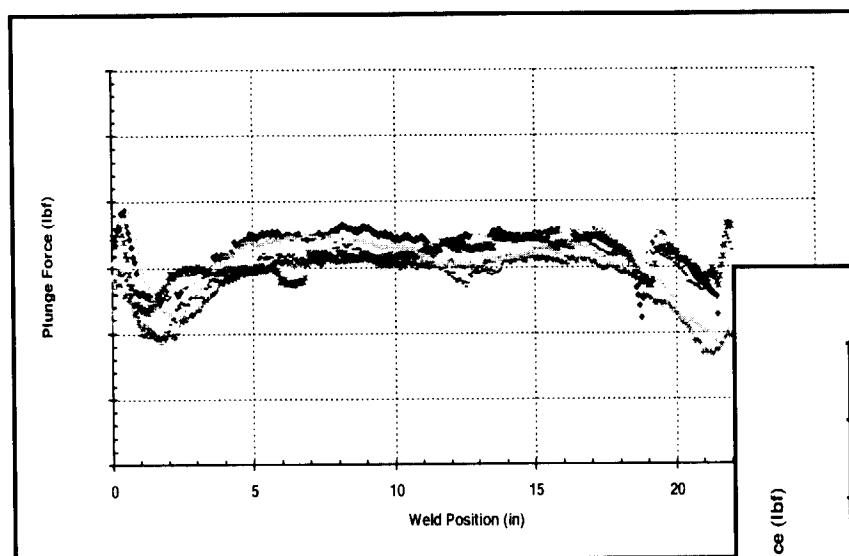


- Schedule selection is the best compromise between the following factors:
 - Process stability
 - Mechanical strength
 - NDE response
 - Machine capability
- The nominal schedule should be near the center of the process envelope to ensure robust performance to variations in the manufacturing environment





- Multiple welds are performed with varied setup conditions
- Process information, such as plunge load, is collected and acceptable bounds are established





FSW Process Map Summary LOCKHEED MARTIN

- The weld process performance for a given weld joint configuration and tool setup is summarized on a 2-D plot of RPM vs. IPM
- A process envelope is drawn within the map to identify the range of acceptable welds
- The sweet spot is selected as the nominal weld schedule
- The nominal weld schedule is characterized in the expected manufacturing environment
- The nominal weld schedule in conjunction with process control ensures a consistent and predictable weld performance